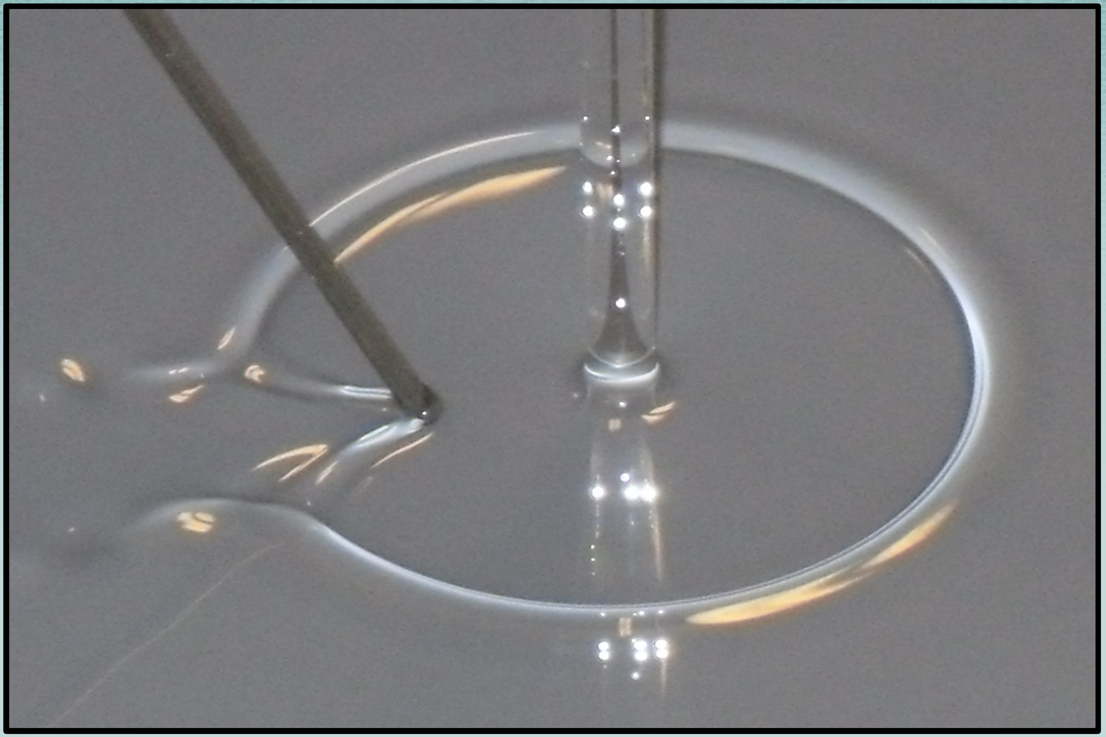
Horizon effects for surface waves

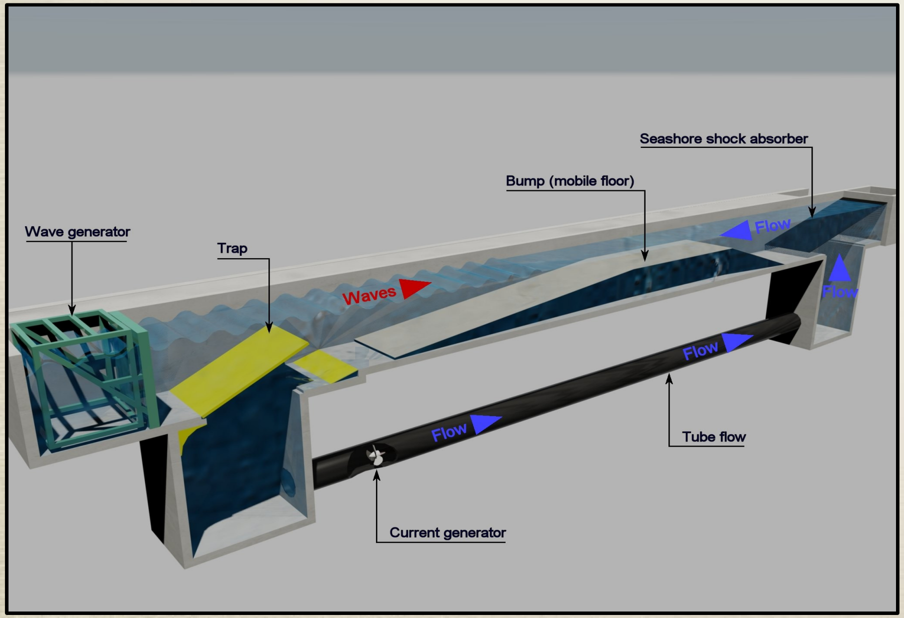


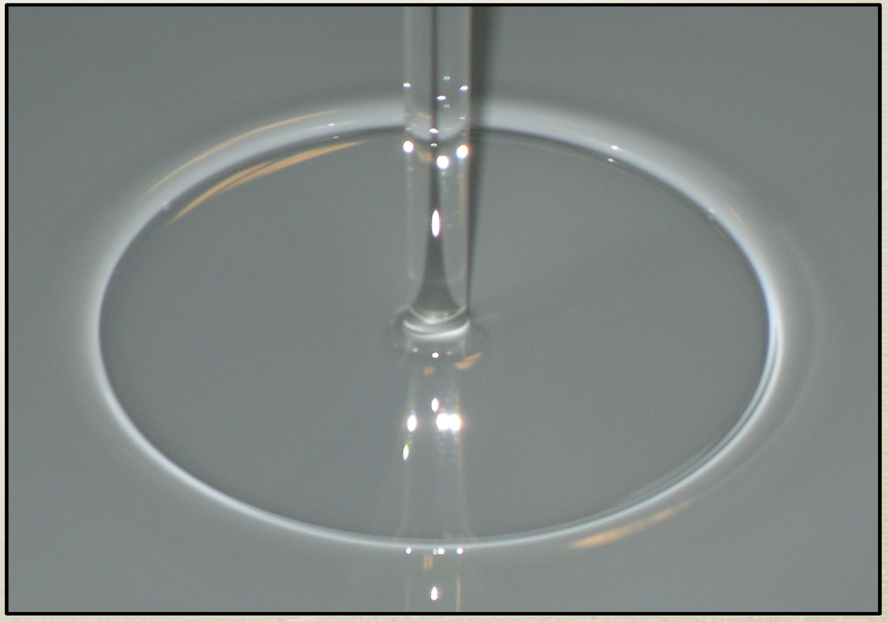
Gil Jannes, Germain Rousseaux, Jennifer Chaline, Romain Piquet, Philippe Maïssa, Christian Mathis, Pierre Coullet

Laboratoire J.-A. Dieudonné,
CNRS - Université de Nice-Sophia Antipolis

Spanish Relativity Meetings, September 2010

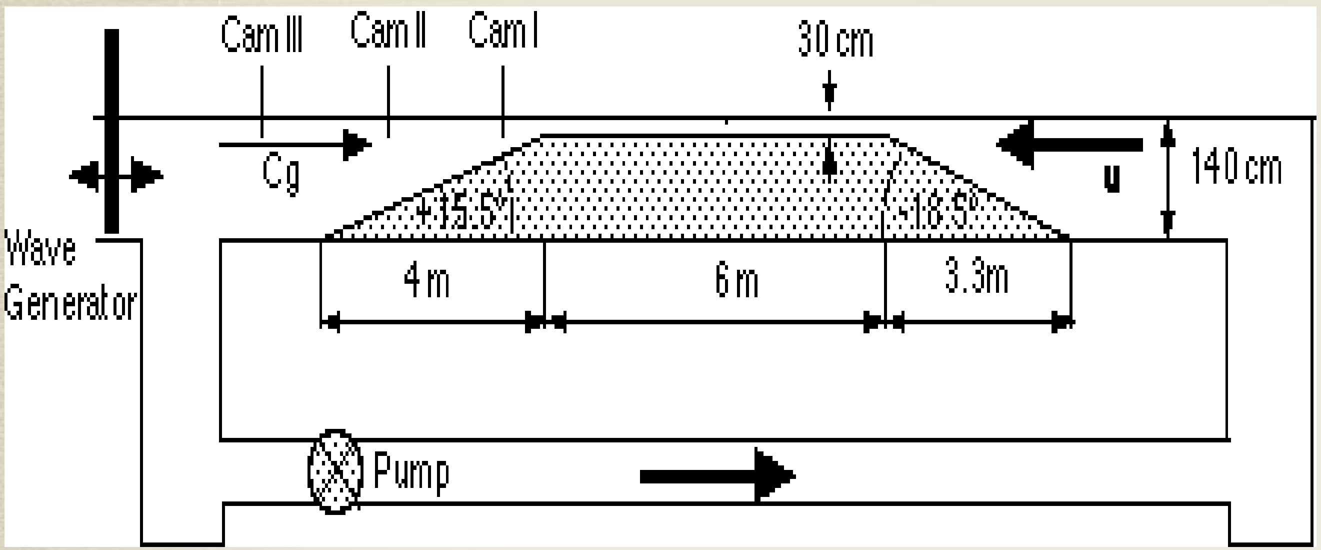
Gravity waves as Black/White Hole Analogues

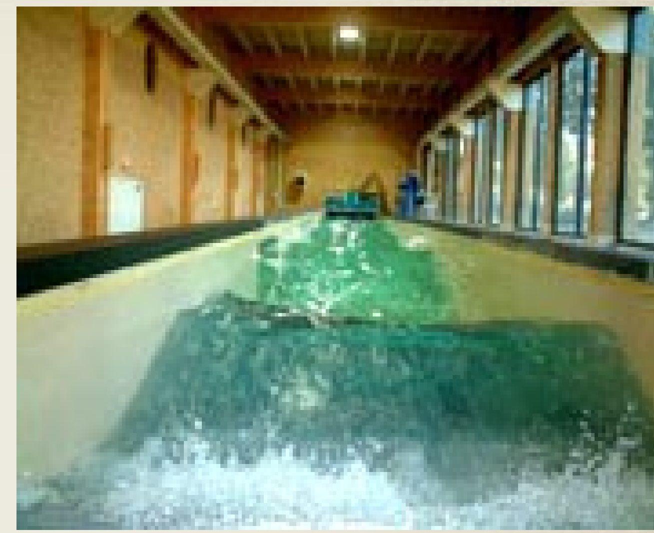


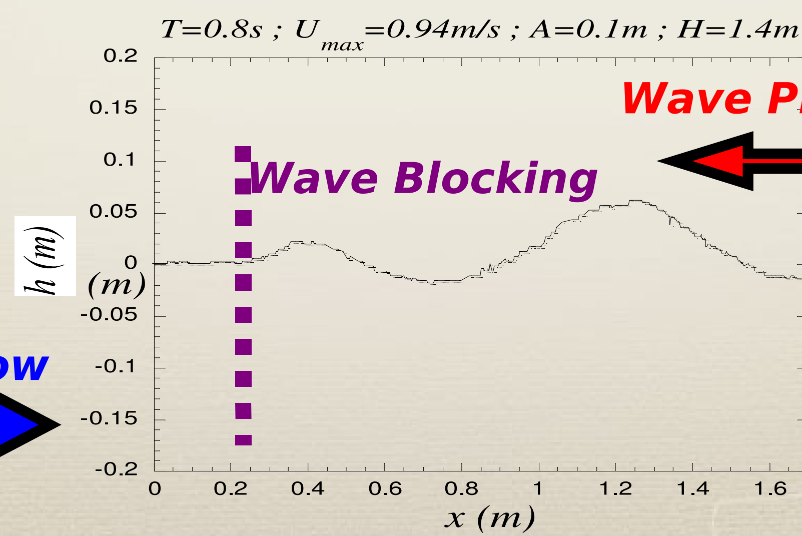


Experimental White Hole Horizon in Wave Channel

Wave Propagation → Ramp ← **Counter Flow**







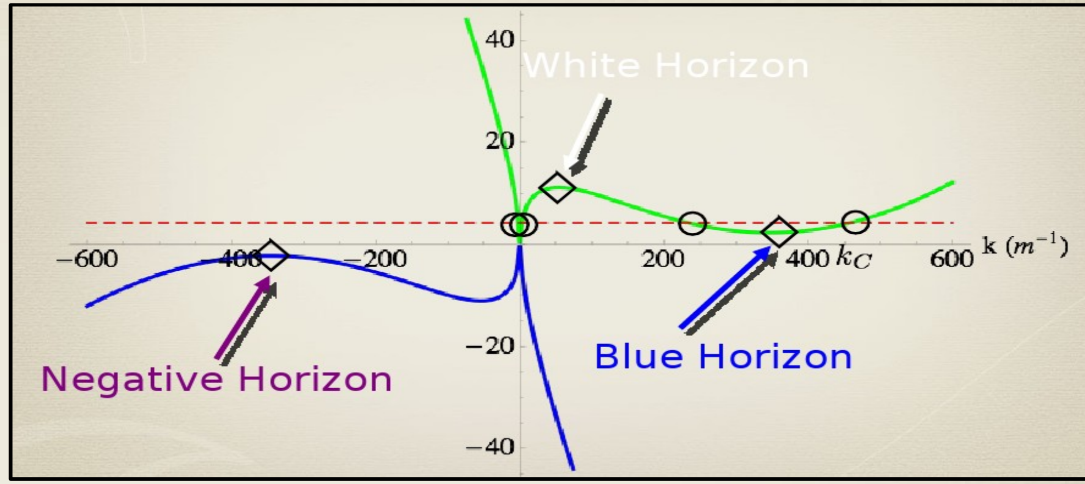
Wave Propagation ←

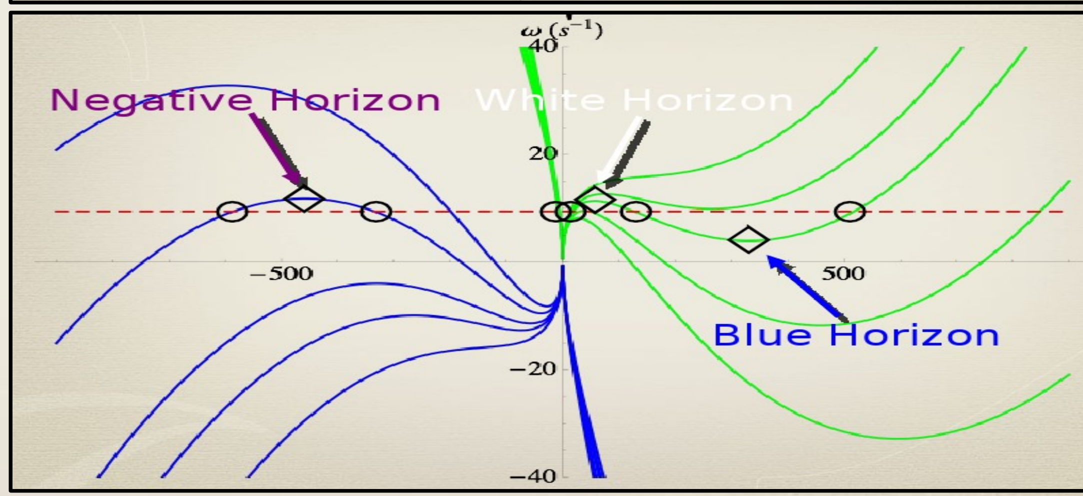
Counter Flow →

Capillo-gravity waves

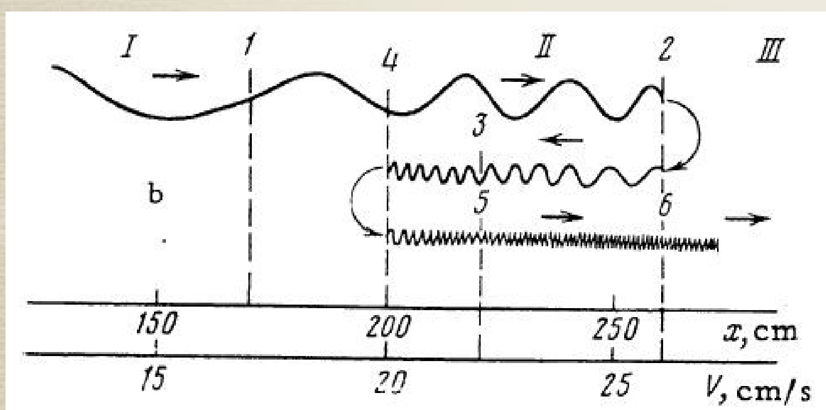
$$\omega = \Omega(k) = Uk \pm \sqrt{\left(gk + \frac{\gamma}{\rho}k^3\right)\tanh(kh)}$$

(Rousseaux *et al*, NJP2010)





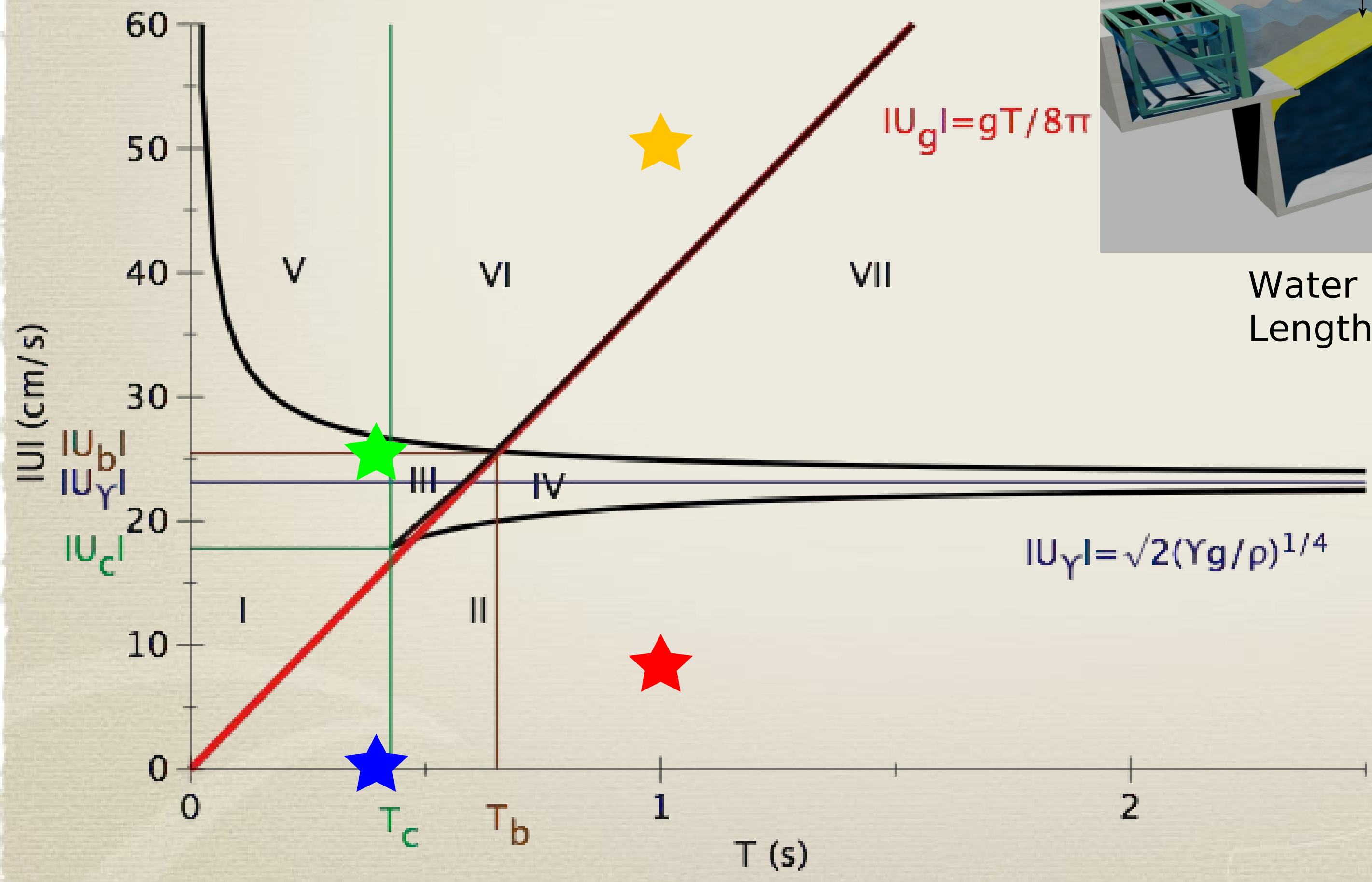
Varying counter-flow

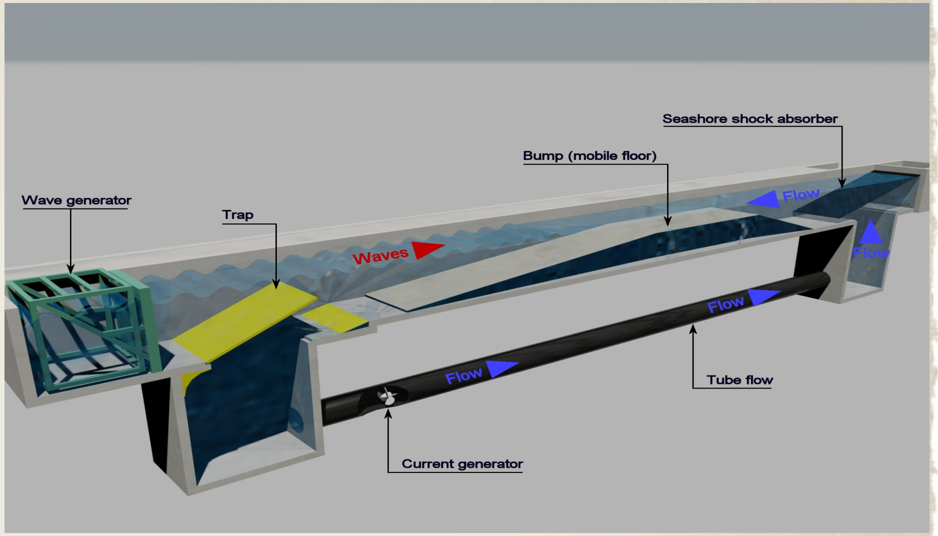


Double bouncing
(Badulin *et al*, 1983)

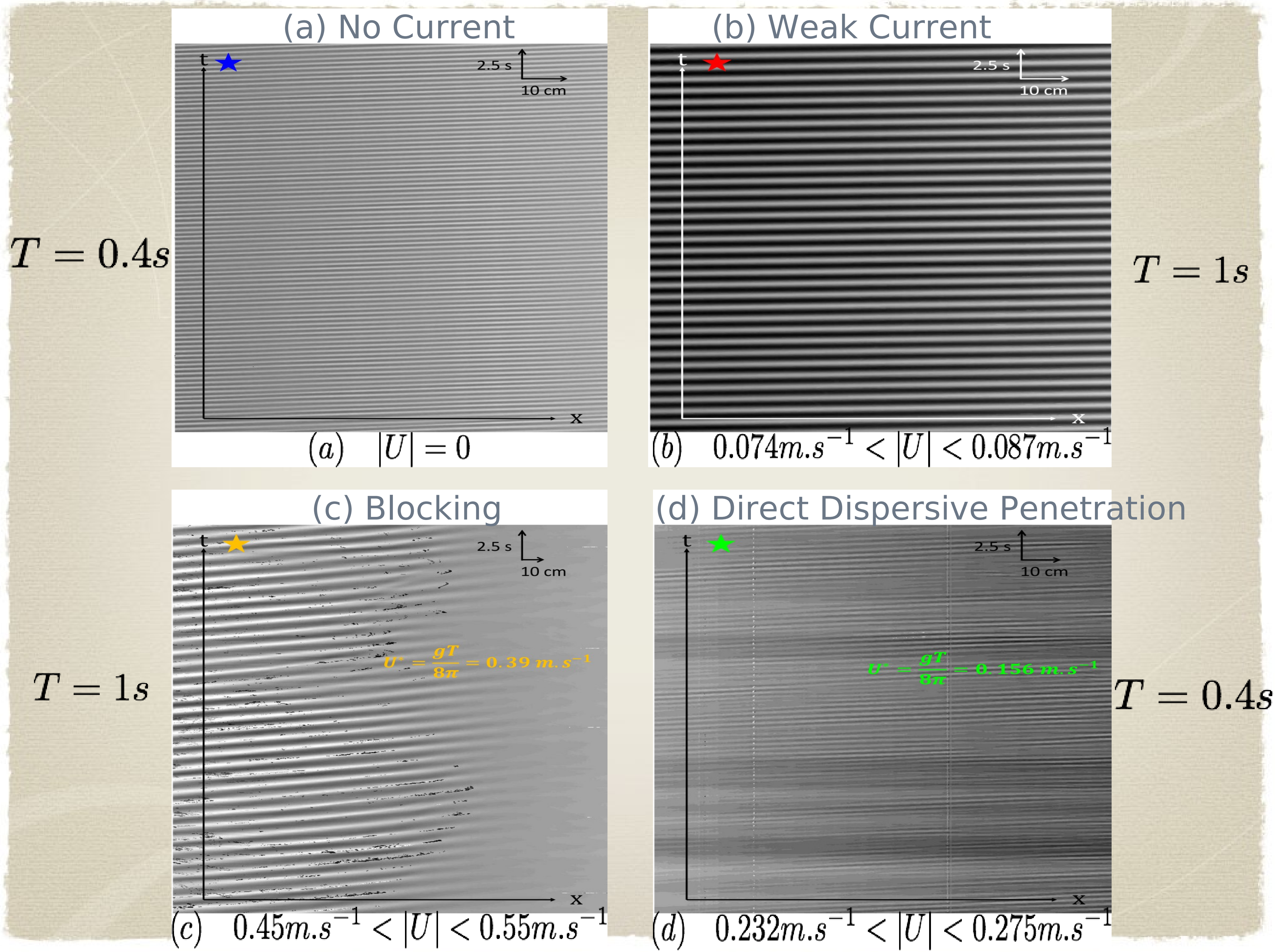
Influence of surface tension: Benchmark Experiments

$$\omega = \Omega(k) = Uk \pm \sqrt{\left(gk + \frac{\gamma}{\rho}k^3\right)} \qquad kh >> 1$$



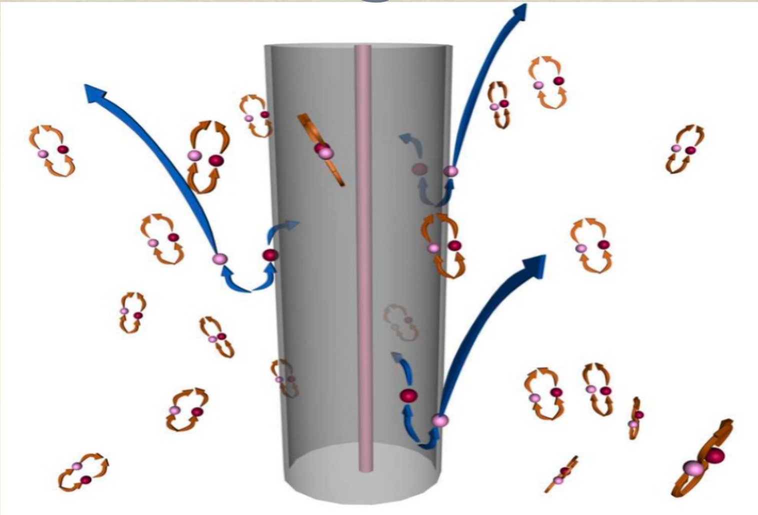


Water H=0.5-1.6m - Slopes 7.5/18.5º
Lengths 8/4.8/3.3m



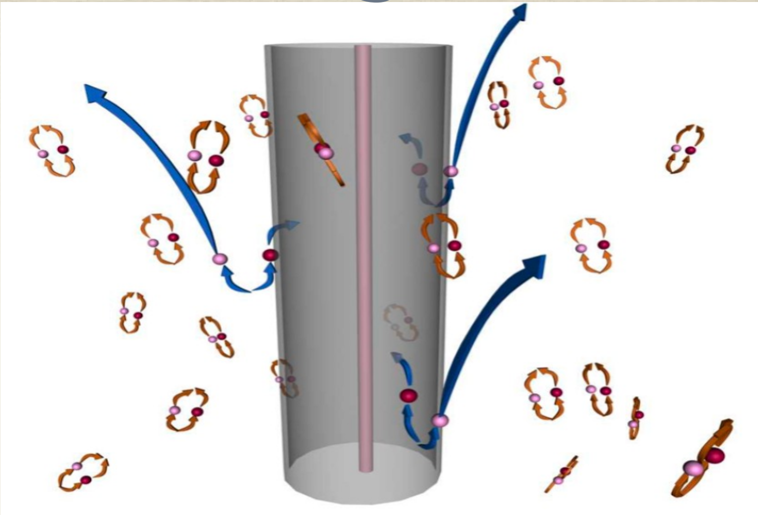
(a) No Current
(b) Weak Current
(c) Blocking
(d) Direct Dispersive Penetration
$T = 0.4s$
$T = 1s$
$T = 1s$
$T = 0.4s$
t
x
2.5 s
10 cm
$(a) \quad |U| = 0$
$(b) \quad 0.074 m.s^{-1} < |U| < 0.087 m.s^{-1}$
$U^* = \frac{gT}{8\pi} = 0.39\ m.s^{-1}$
$(c) \quad 0.45 m.s^{-1} < |U| < 0.55 m.s^{-1}$
$U^* = \frac{gT}{8\pi} = 0.156\ m.s^{-1}$
$(d) \quad 0.232 m.s^{-1} < |U| < 0.275 m.s^{-1}$

Hawking Effect



Classical ingredient:
(Stimulated) appearance of negative frequency modes

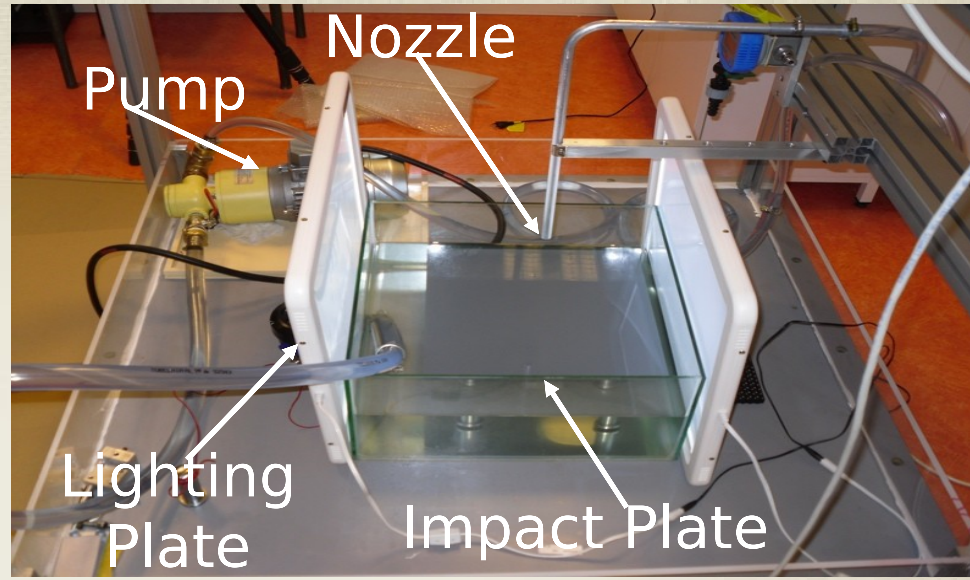
Hawking Effect

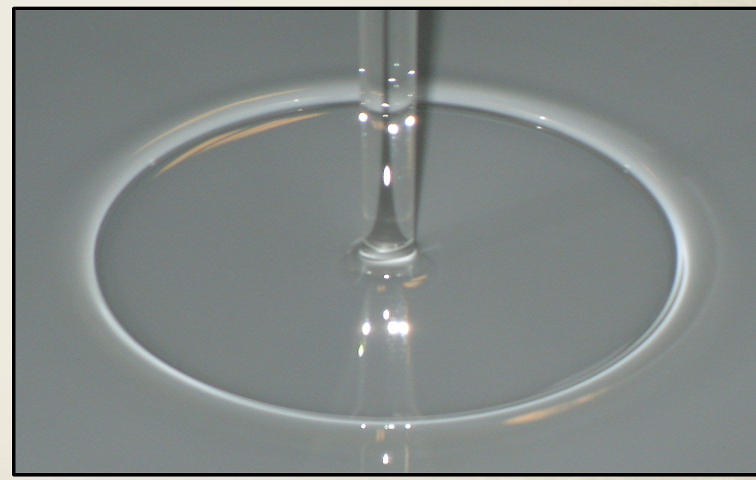


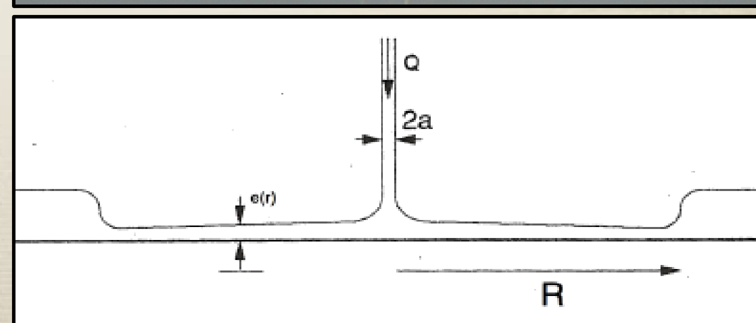
Classical ingredient:
(Stimulated) appearance of negative frequency modes

Asterix Effect

Experimental Setup for the Circular Jump







Dispersion relation

$$(\omega - Uk)^2 = \left(gk + \frac{\gamma}{\rho}k^3\right)\tanh(kH)$$

γ: surface tension

Deep water (wave channel): kH>>1

$$(\omega - Uk)^2 \approx gk + \frac{\gamma}{\rho}k^3$$

- Always dispersive (subluminal)

  $(c = \sqrt{g/k})$

- Not tunable

Shallow water (circular jump): kH<<1

$$\begin{aligned}(\omega - Uk)^2 &\approx gHk^2 + \left(\frac{\gamma H}{\rho} - \frac{gH^3}{3}\right)k^4 \\ &= c^2k^2 + c^2\left(l_c^2 - \frac{H^2}{3}\right)k^4\end{aligned}$$

l_c: capillary length

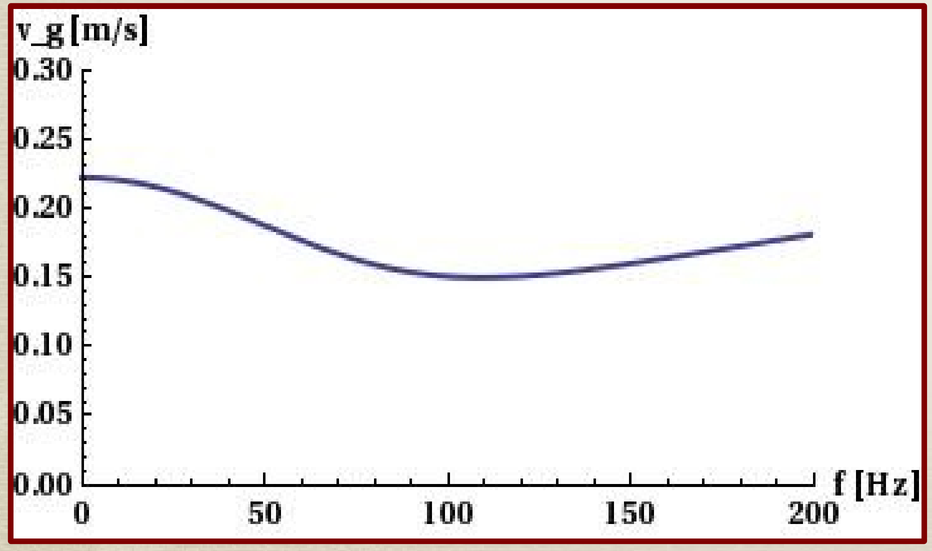
- Relativistic + tunable dispersion
- Superluminal for sufficiently small H
- Probe robustness of black hole physics / Hawking radiation?

Dispersion relation: graphics

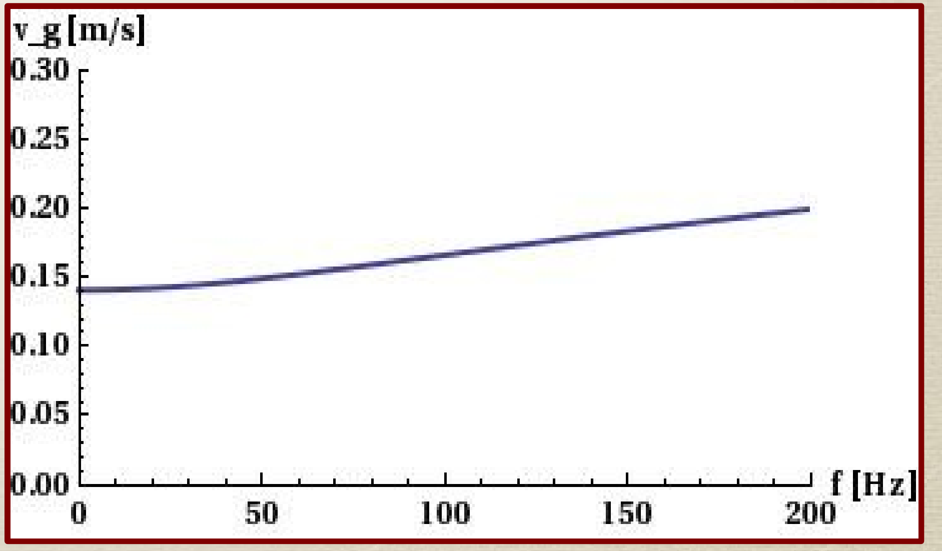
Silicon oil

- viscosity $\nu = 20cS = 20\nu_{\text{water}}$
- surface tension $\gamma = 0.0206N/m \approx \frac{1}{3}\gamma_{\text{water}}$
- density $\rho = 950\ \text{kg/m}^3$
- capillary length $l_c = \sqrt{\gamma/g\rho} = 1.49mm \approx \frac{1}{2}l_{c(\text{water})}$

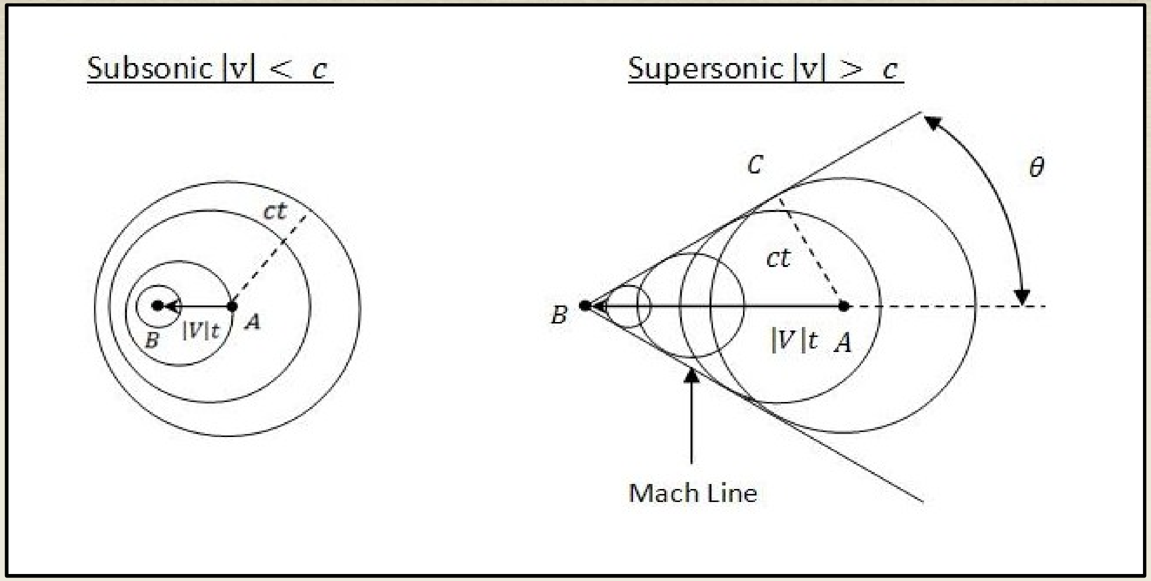
H=5mm



H=2mm



White hole: Mach cone

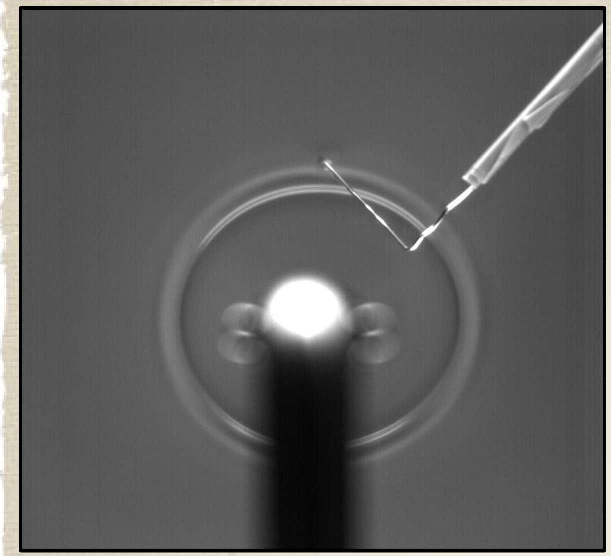


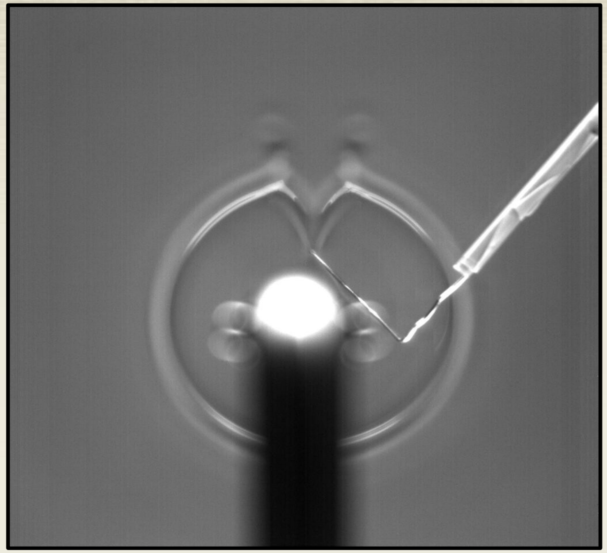
$$\sin\theta = \frac{c}{|V|} = \frac{1}{M} \qquad (c = \sqrt{gH})$$

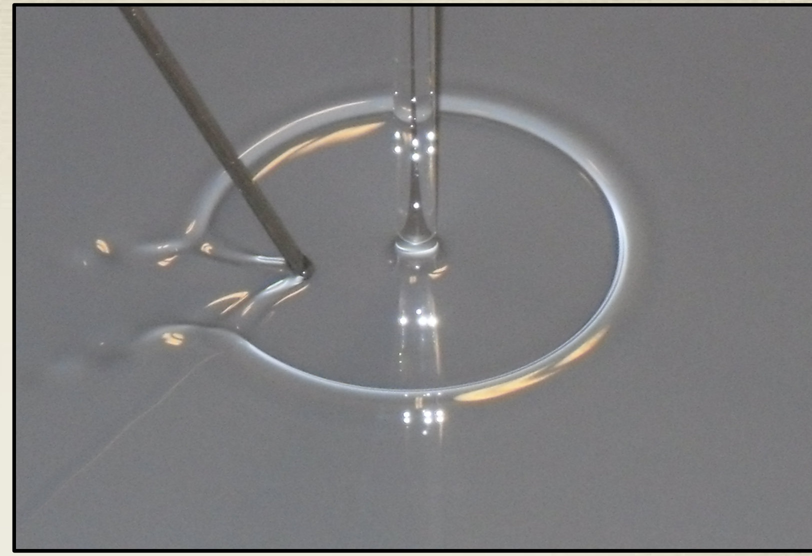
- Supersonic region $(|V| > c)$ $\theta \in \left[0, \frac{\pi}{2}\right]$
- Subsonic region $(|V| < c)$ θ complex $\rightarrow$ Mach cone disappears
- Horizon $(|V| = c)$ $\theta = \frac{\pi}{2}$

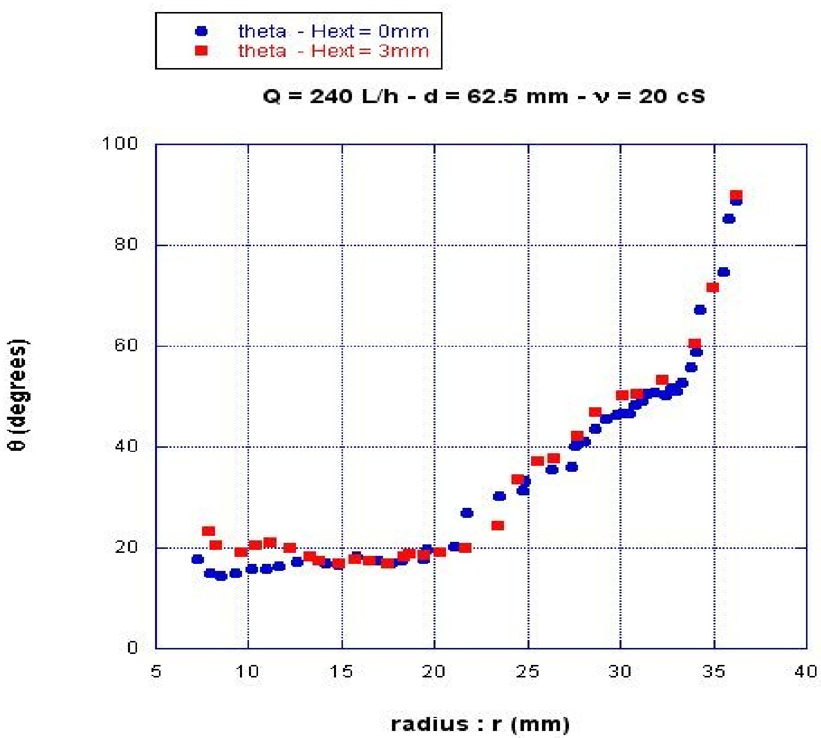
Saddle-node bifurcation (Rousseaux et al, PRL2009)

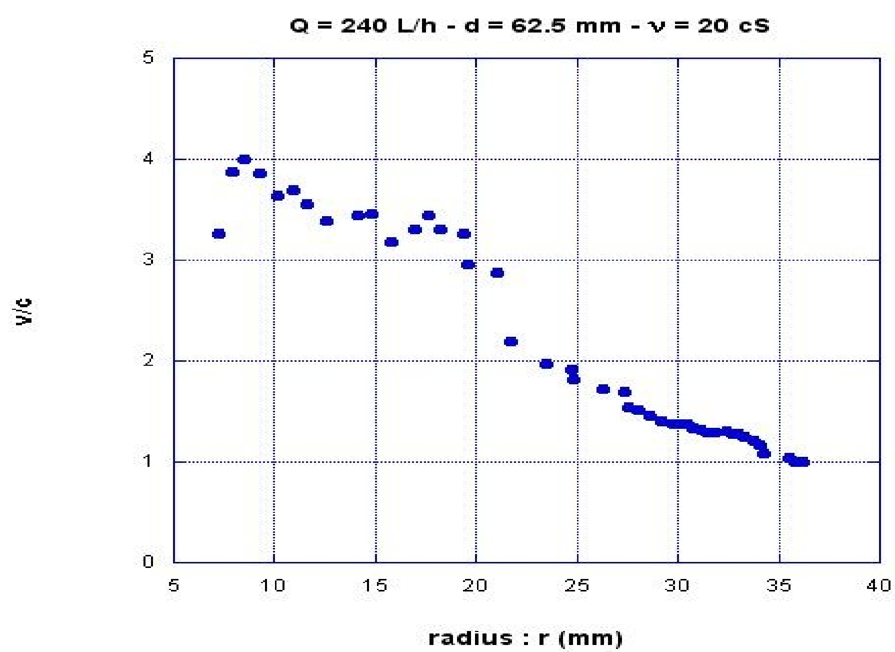
Mach cone: experimental measures



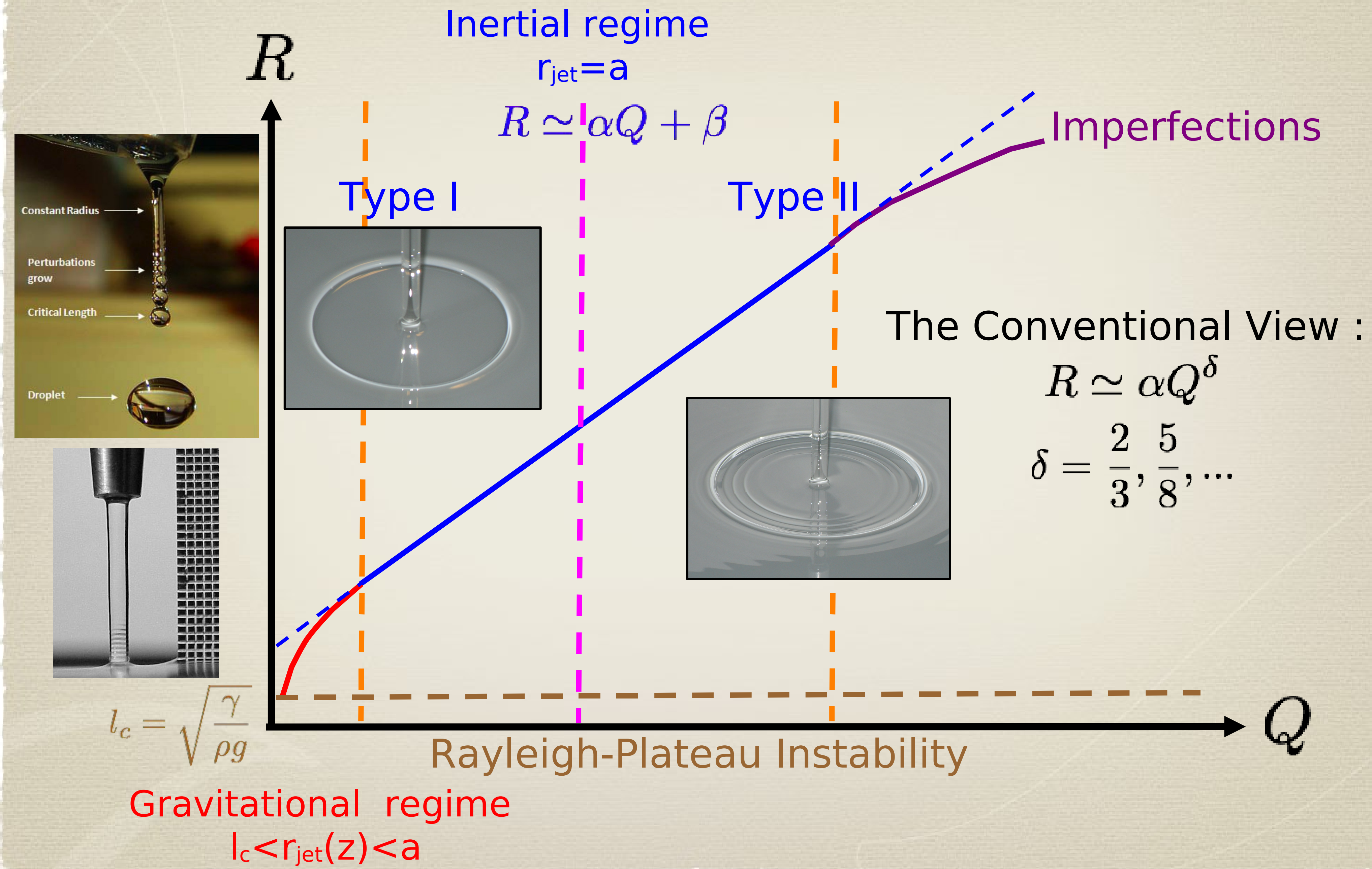








Different regimes?



Conclusions

Wave channel (kH>>1):

- Direct dispersive penetration across horizon
- Due to surface tension at very small scales
- Rousseaux *et al.*, NJP2008, PRL2009, NJP2010

Circular hydraulic jump (kH<<1):

- Relativistic + tunable dispersion
- White hole (Mach cone)
- Small H = most interesting regime for analogue gravity?
- Even from purely fluid mechanics point of view, work on circular jump is in its infancy
- Soon on the arXiv...